Upper Ocean Mixing Due to Nonlinear Internal Waves Over the Continental Shelf

Timothy P. Stanton
Oceanography Department
Naval Postgraduate School
Monterey, CA 93943-5000
phone: (831) 656 3144   fax: (831) 656 2712   email: stanton@oc.nps.navy.mil
Award#: N0001497WR30045

LONG-TERM GOALS

My long term goals are to observe and model internal wave, surface gravity wave, and boundary layer processes which contribute to turbulent mixing in the coastal ocean using new instrumentation techniques.

SCIENTIFIC OBJECTIVES

Scientific objectives of this project are to study the mechanisms by which internal tides and associated Solitary Internal Waves (SIW) contribute to turbulent mixing and cross-shore transport in the pycnocline and ocean mixed layer. Inshore of the shelf break, SIW trains appear to be widespread, and their strong pycnocline displacements, velocity pulses and strain signatures impact a wide range of upper ocean processes. The dynamic stability of SIWs as they propagate shoreward and shoal in coastal regions needs to be understood to correctly model the impact of SIW fields on the upper water column. Secondary objectives are to characterize the displacement form of coastal solitons, and to investigate their interaction with surface gravity waves.

APPROACH

A three week observation of the upper ocean near the shelf break off northern Oregon was made from FLIP in October 1995, while it was tri-moored in 150m of water during the Coastal Ocean Probing Experiment (COPE), run by NOAA's Environmental Technology Laboratory. Over 18000 profiles of temperature, salinity, and thermal and kinetic energy dissipation rates were measured by an automated Loose-tethered Microstructure Profiler every 80 seconds, allowing the upper ocean stratification and turbulence levels to be observed. Five *in situ* measurements of (u,v,w,T,C) were made across a 8m aperture spanning the shallow, strongly stratified pycnocline, while a high speed five beam Broadband Acoustic Doppler profiler defined the velocity structure below the *in situ* array. These measurements were optimized to study energetic solitons which were generated near the shelf break and propagated shoreward past FLIP.

WORK COMPLETED

Reduction of the large LMP and BADCP profile timeseries into binned and calibrated profiles has been completed. Processing of the current sensor timeseries required a significant programming effort to identify and correct a data acquisition buffer problem. These data have been shared with other COPE investigators looking at surface effects of the internal wave field. Additional processing had to be executed to transform the three component velocity measurements

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **1998**	2. REPORT TYPE	3. DATES COVERED **00-00-1998 to 00-00-1998**

4. TITLE AND SUBTITLE **Upper Ocean Mixing Due to Nonlinear Internal Waves Over the Continental Shelf**	5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Naval Postgraduate School,Department of Oceanography,Monterey,CA,93943**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES
See also ADM002252.

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**4**	

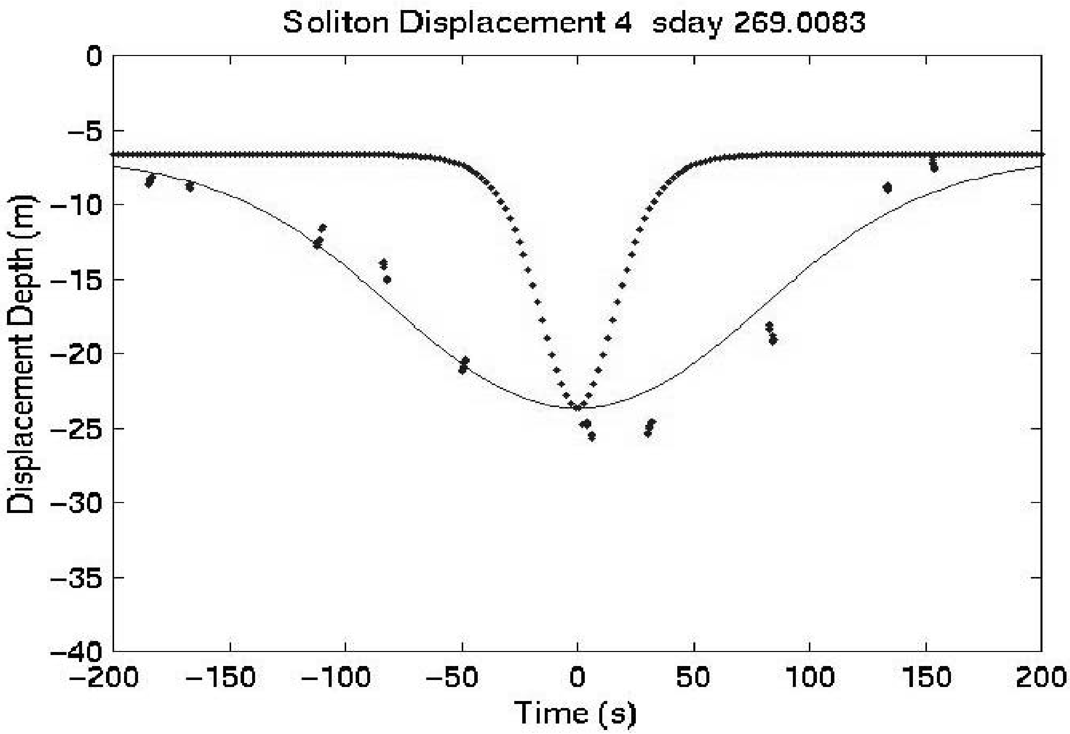
into vertical coordinates using an inertial attitude package on the *in situ* sensor array, due to strong tilts of the instruments forced by the very large velocities associated with the solitons. A workshop of the COPE participants was hosted at NPS in August 1996 to disseminate data sets and work on collaborations. Analysis of a 24 hour segment of data characteristic of the strongest internal tidal energy has been published in GRL (Stanton and Ovstrovsky 1998). Nearsurface current timeseries from several representative Solitary Iinternal Wave (SIW) packets through the three week observation period were compared with radar backscatter observations made by the NOAA ETL group in Kropfil *et al*, 1998. A more comprehensive manuscript investigating the variation of SIW structure over a spring / neap cycle, and assessing the shear stability of SIW groups and the net effect on upper ocean mixing has been submitted (Stanton 1998). These results were also presented at the 1998 Ocean Sciences meeting.

RESULTS

The strong, shallow, salinity stratified surface structure at the COPE site provided conditions which supported large amplitude soliton packets on the steep leading edge of each cycle of the semidiurnal internal tide during the observation period. Stanton and Ostrovsky, 1998, show that during periods of strongest offshore tidal forcing, and greatest internal tide amplitude, the SIW displace the pycnocline down approximately 20m from it's 7m initial depth, causing cross-shore surface currents in excess of 75 cm/s. A single SIW displacement in Figure 1 measured near spring tidal forcing illustrates the improved fit with the second order, combKdV model, in comparison with the lower order KdV form for the displacements. The observed SIW packets also show only a weak width / amplitude dependence which is consistent with the combKdV model but not the KdV form.

Changes in turbulent kinetic energy dissipation rates and vertical diffusivities by SIW activity are explored in Stanton 1998, where several SIW groups are analyzed during a neap to spring tidal forcing cycle. The SIW during the weaker tidal forcing were characterized by low amplitude displacements (4-8m), highly variable wave crest directions, high curvature wavefronts and frequent interfering wave events, which in turn resulted in high local dissipation rates. In contrast, under spring tidal forcing, the wave fronts were long-crested (with coherent wave fronts spanning the 50km width of the radar observations), and the SIW displacements were 5 - >20m downward from the 6m deep pycnocline depth prior to the arrival of the SIW group. Each SIW displacement rapidily increased the turbulent thermal diffusivity of the pycnocline by at least an order of magnitude, but the largest increases in dissipation and vertical diffusivity were seen later in the SIW group as wave fronts crossed and nonlinearly interacted. Changes in vertical diffusivities as a strong SIW group passed the observation point are shown in Figure 2.

Kropfli *et al* analyzed land-based doppler radar data operated by ETL to study the modulation of backscatter intensity and doppler frequency caused by the highly nonlinear SIW packets. These observations show that the minimum surface backscatter intensity occurs during the maximum of the SIW displacement (and surface current), rather than the commonly believed result that this region of maximum horizontal strain would have maximum backscatter strength.



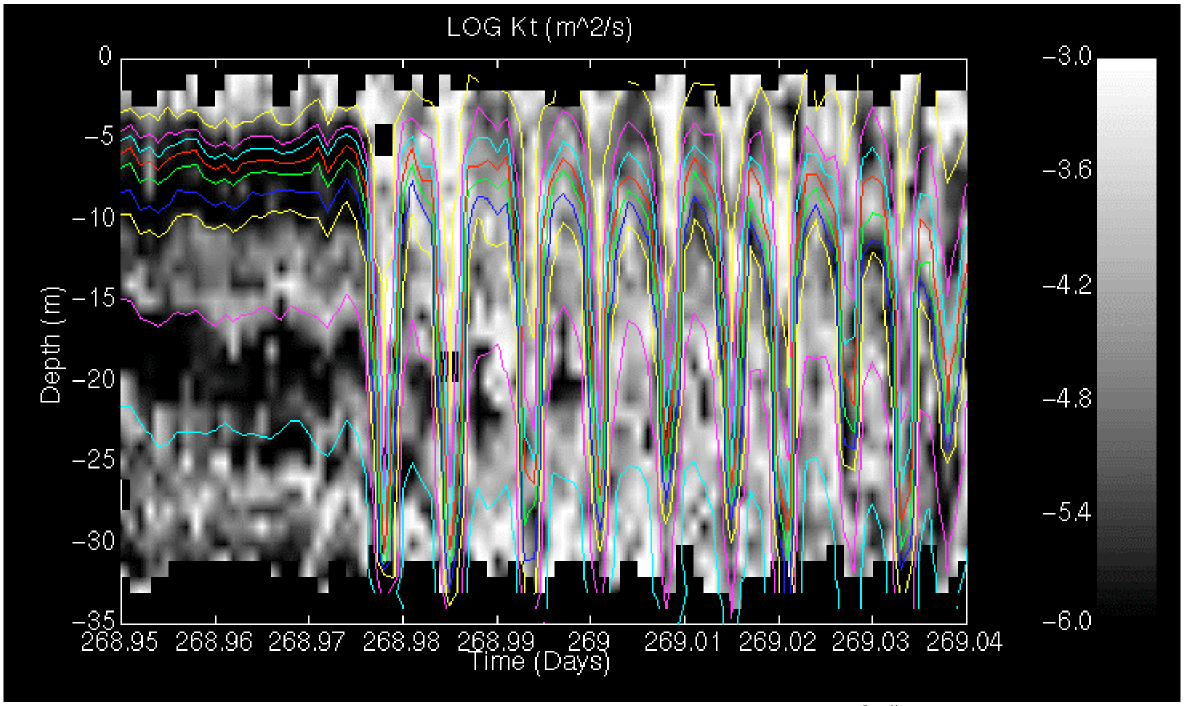
Figure(1) Observed displacement of the pycnocline near the stratification maximum compared with the combKdV model fit (solid line) and the lower order KdV equation fit (dotted line). The improved fit with the higher order model is clear. The 10-25m downward displacements from the 7m initial depth pycnocline represent record-breaking nonlinearity in geophysical waves.

IMPACT / APPLICATION

Solitons associated with internal tidal energy are ubiquitous over stratified coastal shelves. There are few detailed observations of SIWs due to their short period and the short duration of the packets. The combination of the strongly stratified site, the stable platform provided by FLIP, and continuous spatial radar coverage of the site are providing unique insights into the properties of these wave packets and their effects on surface water mass displacement and vertical mixing in the upper coastal ocean.

TRANSITIONS

This research was a component of the DoD funded radar remote sensing project, COPE, managed by the NOAA ETL laboratory, which was designed to broadly study environmental effects impacting surface scatter of high frequency radars. Data from the experiment have been made available to investigators studying radar backscatter properties of the ocean, air-sea interactions in coastal regions, and studies of the ocean “thermal skin”.



Figure(2) Profile timeseries of vertical thermal diffusivity (m^2s^{-1}) estimated from thermal microstrucure and mean tempertaure gradient measurements made with the LMP. The temperature isotherms have been superimposed to show the SIW displacements which propagated shoreward past the observation site.

RELATED PROJECTS

Data from this project are being used in on-going optical (Eric Bock at WHOI and Tetsu Hara at URI), and radar backscatter studies (Bob Kropfli and Lev Ostrovsky at ETL and Chapman at JH-APL), and to meet the objectives of air-sea interaction projects.

REFERENCES / PUBLICATIONS

Kropfli, R. A., L. Ostrovsky, T. Stanton, E. Skirta, and A.N. Keane , "Relationships Between Strong Internal Waves in the Coastal Zone and their Radar Signatures", J. Geophys. Res., 1998 in press.

Stanton, T. P. and L. Ostrovsky, 1998. Observations of highly nonlinear, tidally forced solitons over the continental shelf. GeoPhys. Res. Lett. Vol25, No 14, 2695, 2698.

Stanton, T. P., "Upper Ocean Mixing by Highly Nonlinear Internal Solitons Over the Contineta1 Shelf.", 1998. Submitted to JGR.

WEBSITE http://www.oc.nps.navy.mil/~stanton/turblab.html